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TITLE PHYSICAL INVENTORY VERIFICATION EXERCISE FOR A HIGHLY ENRICHED URANIUM FABRICATION FACILITY

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PHYSICAL INVENTORY VERIFICATION EXERCISE FOR A HIGHLY ENRICHED URANIUM FABRICATION FACILITY

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1. INTRODUCTION

The International Atomic Energy Agency, in collaboration with the US Support Program (POTAS), has developed and conducted a training exercise simulating a physical inventory verification (PIV) at a highly enriched uranium (HEU) fabrication facility. This exercise is part of a series sponsored by the POTAS program, including PIVs at light-water reactors and plutonium fabrication facilities.[1,2] The first HEU exercise took place in September 1985 at Los Alamos National Laboratory and a second is scheduled for Spring, 1987 at JRC, ISPRA.

The main objectives of these exercises are:

1. to provide the opportunity for inspectors to test and evaluate the use of nondestructive assay (NDA) equipment and computer software under conditions similar to those found during actual inspections;

2. to use the data generated to evaluate different inspection procedures and strategies; and

3. to exchange ideas on PIV procedures between the three operations divisions.

Because the exercises are conducted in a neutral environment, free of the time pressure often found in actual inspections, it is possible for the inspectors to achieve the course objectives.

2. FACILITY DESCRIPTION

The participants performed verification activities on an inventory of HEU materials that are representative of those found in HEU fuel fabrication facilities. The simulated facility, designated as LA-HEU, Ltd., was designed to manufacture

1. MTR fuel elements and plates,
2. Triga-type (ACRR) elements,
3. Nickel-coated uranium metal disks, and
4. Uranium-carbide beads.

To produce these product items, the facility received the following input materials:

1. Uranium metal buttons,
2. UF_6 cylinders (5A size), and
3. UO_2 powder.

At the time of the PIV, the following intermediate process materials were in the facility:

1. U_3O8 powders,
2. "U mixed with carbon" scrap, and
3. Uranium-aluminum alloys in the form of "billets."

3. SUMMARY OF ACTIVITIES

For the first exercise, eight inspectors representing all three operations divisions divided into two teams of four, with each team independently verifying the simulated physical inventory using NDA equipment in routine use by the Agency. A ninth inspector acted as coordinator between the two teams. A Los Alamos staff member played the role of facility operator. A summary of the nuclear material inventory and NDA methods used during the exercise is presented in Table I. Table II lists the NDA equipment available to the inspectors.

The exercise entailed three training phases. The first phase covered instrument calibration, normalization, and evaluation. The second phase covered stratification, sampling plan, random selection of items and NDA measurement, and reviewing inventory verification procedures. The final phase

TABLE I

PHYSICAL INVENTORY SUMMARY
AND NDA MEASUREMENT METHODS

Material Category	No. Items	Total Uranium (g)	Measurements Performed[a]
Metal disks	7	15 000	AN, WT, ENR
Metal buttons	6	11 800	AN, WT, ENR
UF_6 cylinders	3	44 000	WT, ENR
UO_2 powders	6	17 000	AN, WT, ENR
U AL billets	120	9 100	AN, WT
U_3O_8 powder	14	12 000	AN, WT, ENR
Scrap powder	28	9 500	AN, WT
MTR fuel elements	40	9 400	AN, WT, GAMMA
MTR fuel plates	275	3 600	AN, WT, GAMMA
ACRR fuel elements	65	9 600	AN
U C beads	14	25 300	AN, WT, ENR

[a] AN - Active neutron coincidence counting; WT - Weight; ENR - Enrichment; GAMMA - Gamma-ray measurement (total ^{235}U)

TABLE II

AVAILABLE EQUIPMENT FOR EXERCISE

Instrument	No. Available
AWCC - Active Well Coincidence Counter	2
PMCN - Portable MCA with NaI Detector	2
PMCG - Portable MCA with Ge Detector	2
ULTG - Ultrasonic thickness gauge	2
Balance, 0-10 kg	1
Balance, 0-50 kg	1
URAM [UF_6 receipts assay monitor (URAM) designed for UF_6 cylinder measurement was considered as operator measurement system for this exercise]	1

included evaluation of verification results and drawing conclusions. The exercise lasted eight working days. Days 1 and 2 included reviewing the operation of all the instruments and performing selected calibration checks. At the end of the second day, each team was given an item inventory listing, which they used to stratify the inventory and select the items for verification measurements. The next four days were spent making measurements. On day 7 the data were analyzed for operator-inspector differences and the uncertainties of the differences. Using Agency criteria for definition of outliers, they identified anomalies for later discussion with the facility operator. When the analyses were complete, the information was transferred to an inspection report form. The eighth and final day was spent in discussing discrepancies with the operator, reviewing the exercise among the participants, and drafting a summary report.

All of the activities were described in a manual, which was reviewed by all the participants. It includes the following specific NDA procedures and working papers:

- Procedures and working papers for stratification, sampling plan, and random selection of items.

- Procedures and working papers for use of AWCC for quantitative verification of materials containing UO_2, U_3O_2, U/C beads, etc.

- Procedures and working papers for use of PMCN for enrichment verification of different material types.

- Procedures and working papers for use of PMCG and ULTG for enrichment measurement of UF_6 cylinders.

- Procedures and working papers for use of PMCN for quantitative verification of MTR fuel elements and plates.

- Procedures and working papers for use of UF_6 Receipt Assay Monitor "URAM" and Authentication.

- Procedures and working papers for combining enrichment and weighing to conclude quantitative verification.

- Procedures and working papers for reporting quantitative verification carrying out D-statistics and preparing statement on operator-inspector differences.

3. PHASE I - INSTRUMENT CALIBRATION, NORMALIZATION, AND EVALUATION

The equipment had been calibrated before the exercise by LANL staff. The purpose of Phase I was to inform the IAEA staff of how the calibrations were performed. Each team repeated a small number of calibration measurements and compared them to the stated values.

3.1 Active Well Coincidence Counter (AWCC)

This versatile NDA instrument[3] works by inducing fissions in the ^{235}U contained in a sample and counting the resultant fission coincidence neutrons. The fissions are induced by an (α,n) source (AmLi) with the coincidence neutrons being separated from (α,n) neutrons by the counting electronics.

Because of the wide variety of samples encountered in this PIV, the AWCC was reconfigured in four different geometries as described in Table III. It was important the verification

TABLE III

Configuration	Items Measured	Geometry Description
Mode 1	Metal disks, U_3O_8 cans, Metal button	23 cm high x 14 cm diam counting chamber
Mode 1-thermal	U AL billets	23 cm high x 14 cm diam counting chamber with cd absorber removed
Mode 2	UO_2 in 2-L plastic bottles UC beads in 2-L plastic bottles	Expanded counting chamber 35 cm high
Horizontal	MTR fuel elements and plates, ACRR fuel elements	Turned on its side with special adapter insert

measurement used the calibration equation for the matching geometry and material type.

The form of the calibration equation varied with material type. The oxides, metals, and carbide beads were fit to a quadratic equation while the MTR fuel elements required a form, $a_o(1 - e^{a_1 M})$. All the AWCC calibration equations were programmed into an HP85 which collected and analyzed the data.

2. Portable MCA with NaI Detector - PMCN

This equipment was used for two purposes, enrichment measurements and total ^{235}U determination for MTR materials.

The PMCN measured the enrichment of the metals, oxides, and carbide beads. In principle, one calibration should apply to all material types for a fixed detector viewing angle, providing correction for the differences in chemical form is applied.[4] This correction is 1-3% for the above materials. However, another complication arose because the items were stored in containers with differing wall attenuations. In some cases, it was difficult to determine the exact correction.

This introduced a systematic uncertainty on the order of 2% for UO_2 powders and UC beads.

A second use of the PMCN was to measure the ^{235}U content of MTR fuel elements and plates. The 185.7-keV gamma rays were measured in a well-controlled geometry. Corrections for effects due to attenuation, geometry, and scattering were calculated using the procedure described in STR-146.[4] These corrections were applied to the data and the ^{235}U mass was calculated. As an extension of this approach, the transmission through the element was measured and used to determine total uranium.

3.3 Portable MCA with a High-Resolution Germanium Detector - PMCG

The portable MCA with high-resolution Germanium detector (PMCG) was used with an ultrasonic thickness gauge to measure the percent enrichment of UF_6 cylinders. The cylinder wall thickness at the gamma-ray measurement point was measured with the thickness gauge. A gamma spectrum was acquired using PMCG equipment with the specialized software developed at Los Alamos.[5] The software was contained in PROMS, which were installed in MPU board in the MCA. The program set MCA parameters for the measurement, prompted the users through measurement steps and calculated the results. The correction for wall thickness was also applied to the measurement response to obtain the measured enrichment.

4. PHASE II - PIV ACTIVITIES

Because "LA-HEU, Ltd." is a simulated facility, certain assumptions had to be made that would not pertain to an actual PIV. These assumptions were:

1. The records and reports were correct and did not have to be audited,

2. The item check in the vault had already been done and that with seals the continuity of knowledge was maintained, and

3. That no "bias defect" measurements were needed.

Table IV lists the KMPs for the facility. The stratification and sampling plan is presented in Table V. In determining the number of samples, the detection goal quantity was set at 5 kg uranium.

TABLE IV

FACILITY KMP CHART

Facility Code: LAHU   MBA: LAHU

<u>IKMP</u>

A	Input store, metal buttons
B	Input store, UF_6
C	Input store, powder
D	Process
E	Output store, MTR
F	Output store, U/C beads
G	Output store, metal disks

<u>FKMP</u>

1	Receipt
2	Shipment
3	Measured discards, waste, etc.
4	SRD

TABLE V

STRATIFICATION AND SAMPLING PLAN

Stratum	KMP	Material Description	Total Items	N_A[a]	N_V[b]
1	D	U_3O_8	14	5	1
2	G	Metal disks	7	5	1
3	A	Metal buttons	6	4	1
4	D	U AL billets	120	5	1
5	C	UO_2	6	5	1
6	F	UC <1000 g	9	3	1
7	F	UC >1000 g	5	5	1
8	B	UF_6 >6000 g	2	2	2
9	B	UF_6 <6000 g	2	2	1
10	D	Scrap	28	5	1
11	E	MTR elements	40	5	1
12	E	MTR plates	275	2	1
13	E	ACRR elements	65	2	-
			579	50	13

[a] N_A - No. of samples for attribute verification.
[b] N_V - No. of samples for variables verification.

5. VERIFICATION MEASUREMENTS

During a PIV, the Agency is required, if possible, to verify both the total uranium and the ^{235}U mass in the inventory. For this PIV exercise, the two inspection teams verified most of the strata using two different measurement approaches. For example, ^{235}U mass was verified by:

1. an AWCC which gives grams ^{235}U directly and/or

2. An Agency net weight times an Agency measured enrichment times an operator declared uranium concentration.

In a similar way, total uranium was determined by:

1. an AWCC measurement of ^{235}U divid[illegible] an Agency measured enrichment and/or

2. an Agency net weight times an operator declared uranium concentration.

Exceptions to these approaches were MTR plates/elements and the UF_6 cylinders. The MTR plates and elements were measured directly using direct gamma-ray counting for ^{235}U and gamma-ray transmission for total uranium. The ^{235}U contained in the UF_6 cylinders was measured in an operator instrument (URAM) and in turn, the URAM results were authenticated by net weight times enrichment times concentration values.

In all, approximately 60 items were verified independently by both teams using a combination of AWCC, gamma-ray enrichment measurements and weight. Table VI presents typical measurements for UO_2 powders in 2-L plastic bottles.

6. PHASE III -- EVALUATION OF RESULTS AND CONCLUSIONS

The individual verification results, such as are presented in Table VI, were examined for outliers. The criterion for an outlier was taken at four times the combined uncertainties of operator and inspector measurement errors. Nine outliers were detected. In each case, the operator declared value was found to be wrong. Table VII lists these discrepancies. The "operator" corrected the physical inventory listing.

After the outliers had been resolved, the individual results were combined for each stratum and an operator-inspector difference (Di) was determined. The standard deviation about the average stratum difference was taken as a measure of the random uncertainty in Di. Table VIII shows the results for ^{235}U using the AWCC (and the URAM for UF_6 cylinders). Similar tables were generated for the enrichment plus weight and concentration method and for total uranium.

TABLE VI

AWCC MEASUREMENT OF UO_2 POWDER

Sample	Count Time n x t (s)	$\bar{T}$ (counts/s)	$\bar{R}$ (counts/s)	s_R	Assay (g)	Tag (g)	Δ (G)	σ (g)	Δ (%)
CRL 1350 C	3 x 300	8572.70	202.06	3.35	1492.49	1495.00	2.51	38.78	0.17
CRL 1351 C	3 x 300	9018.01	323.43	3.55	2832.03	2730.00	-102.03	64.62	-3.7
CRL 1351 B	3 x 300	8982.94	330.18	3.54	2907.38	2774.00	-133.38	65.99	-4.8
CRL 1351 A	3 x 300	8923.70	330.11	3.52	2906.58	2866.00	-40.58	65.88	-1.4
CRL 1350 A	3 x 300	8961.13	378.40	3.54	3415.00	3420.00	5.00	75.42	0.15

Calibration equation:

$$\dot{R} = 0.1809\ M_{235} - (0.3826 \times 10^{-4})\ M_{235}^2 + (0.5192 \times 10^{-8})\ M_{235}^3$$

TABLE VII

OPERATOR-INSPECTOR DISCREPANCIES FOUND BY IAEA VERIFICATION MEASUREMENTS

Item	Declared Value	Actual Value
UF_6 cylinder	10 684 g ^{235}U	0 g
UC beads	3 791 g ^{235}U	50 g
UC beads	700 g ^{235}U	3 791 g
UC beads	0.684 g U/g sample	0.545
U_3O_8 powder	97.67% enrichment	11.8
U_3O_8 powder	97.67% enrichment	13.3
U_3O_8 powder	97.67% enrichment	17.3
U_3O_8 powder	97.67% enrichment	13.9
U Al billet	137 g ^{235}U	96.0

TABLE VIII

STRATA TOTALS (AWCC MEASUREMENTS)

		Team A			Team B		
Material	Total ^{235}U (g)	O-I (g)		UNC · (g)	O-I (g)		(g)
Metal buttons	11 000	-390	±	219	170	±	143
Metal disks	14 000	-110	±	150	-325	±	151
UO_2	16 500	-322	±	371	-1011	±	385
U_3O_8	3 700	-249	±	226	-423	±	144
UC < 1000 g	6 000	54	±	128	-202	±	211
UC > 1000 g	17 900	-94	±	591	-492	±	525
UF_6	24 300	-44	±	1260	-679	±	1284
U Al billets	8 500	276	±	288	276	±	396
MTR plates	3 300	283	±	288	67	±	34
MTR elements	8 800	-292	±	364	-368	±	124
ACRR elements	3 380	565	±	221	208	±	72
Scrap	8 900	523	±	95	-25	±	263
	126 280	+200	±	1603	-2804	±	1558

enrichment plus weight and concentration method and for total uranium.

7. CONCLUSIONS

1. The operator-inspector difference Di and the associated uncertainties $\sigma(Di)$ for ^{235}U content for each stratum were established for all material types. For material types where the total uranium content could be independently verified, similarly, D-statistics were also performed.

2. The strata were verified by (1) AWCC and/or combined with enrichment measurement and (2) combined weighing and enrichment measurement. In the case where an operator's declaration on the uranium concentration factor can be assumed as verified, the combination of weighing and enrichment measurement resulted in a quantitative statement on ^{235}U and U_{total} content, and the results of D-statistics are comparable with the use of AWCC combined with enrichment.

3. It was shown that the results of AWCC, which measures the ^{235}U content of material can be considered sufficient for quantitative verification of most material types including MTR type fuel elements, scrap, and billets. For material on which an enrichment measurement can be performed, the operator declarations of U_{total} content were also independently verified.

4. The total operator-inspector difference D and the associated uncertainties σ_D for ^{235}U and U_{total} content were determined and found statistically not significant, i.e., no diversion of a significant quantity of nuclear material was detected.

8. DISCUSSION AND RECOMMENDATIONS

The exercise was carried out successfully and found to be very useful for the participants. It helped to review procedures and working papers by a group of experienced inspectors representing all three divisions of operations. The following observations and recommendations were made by the participants.

- It was felt that the exercise was successful and should be repeated 2-3 times enabling wide participation of inspectors who deal with verification of HEU materials.

- A review of the standard calibration manual including procedures and working papers shall be encouraged within the safeguards department.

- The computer software for AWCC shall be standardized.

- More precise balances shall be provided during the next exercise, and procedures for weighing, in particular, determination of tare weight, shall be prepared.

- Computer software shall be developed to help process statistical data analysis of the final results.

- Effort should be made to test and evaluate the use of HLNCC-II for measurement of HEU-UF_6 cylinders. HLNCC-II could be implemented as a "UF_6 Receipt Assay Monitor" type instrument for UF_6 cylinders.

- It would be advisable to continue development on gamma-ray techniques for measurement of MTR elements and plates, using integrated software into the portable Mini-MCA, until it is a fully implemented and field usable inspection technique.

- It was felt that the exercise could be expanded to include the evaluation of the material balance by providing simulated data on beginning inventory and inventory changes.

9. REFERENCES

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